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Fire-Climate Zones of Coastal Alaska

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RESEARCH SUMMARY

This report presents a method for delineating fire-climate zones or areas; application is to coastal Alaska (Forest Service, Region 10). The method uses a multiple regression relationship calculated between a fire-danger parameter and simple climatic averages. The basic principle is to relate the zones to wildfire potential, utilizing data that provide maximum areal coverage. In the present case, the climatic averages were those of rainfall and daily maximum temperature for the May-August fire season. Fire danger was represented by the average seasonal number of days reaching a particular threshold value of the former Buildup Index. The regression, based on data from 18 stations, had a high statistical significance level. It was applied, as a series of curves, to the climatic averages at about 100 additional stations to give estimates of the fire-danger parameter. Fire-climate classes, comprising the fire-climate zones, were defined on the basis of this parameter.

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INTRODUCTION

The extensive forested areas of coastal Alaska (Forest Service, Region 10) have in the recorded past experienced generally minor wildfire occurrence, particularly when compared with that in mainland (interior) Alaska and the lower 48 United States. The maritime influence on the general climate is an obvious tempering factor with respect to fuel moisture, although large spatial differences do occur. Moreover, there is a near absence of lightning activity; wildfire ignition is thus confined, with rare exceptions, to locations of human presence.

Fire-management planning in this region, nevertheless, is presented with a somewhat difficult problem (Noste 1969). Severe burning conditions have occasionally occurred in the past few decades, even in normally wet areas. Thus, while the fire load is usually light, a capability must exist for handling the exceptional situations. A continuing expansion in the human presence, through recreational and logging activities, threatens to bring a more serious fire problem in the future. Contributing, also, would be the accumulating masses of untreated logging slash, which can dry quickly during recurring spells of warm, dry weather.

Fire-management planning has sought to concentrate attention on those areas where the wildfire potential, as influenced by climate, is greatest. Toward this policy, three broad fire-weather zones were devised in Region 10.¹ Though fire danger is monitored, less planning effort is expended with increasing wetness of climate. The present report results from a need expressed for further development and refinement of a fire-danger climatology. It is a condensed, updated version of a preliminary office report.² The purpose here is to present a method of defin-

ing fire-climate classes, employing a parameter of fire danger and simple climatic averages in a multiple regression. These classes are then applied in delineating fire-climate zones for coastal Alaska.

REVIEW OF RELATED WORK

Fire-climate zones or areas have been the subject of several specific studies in the past decade. Their use is included in proposals (Reifsnnyder 1978) addressed to worldwide interests in fire management.

"Fire-season climatic zones" were delineated for mainland (interior) Alaska by Trigg (1971). A mosaic containing 25 zones, based on 16 climate-description classes, was developed. The climate classes were derived from modified Thornthwaite precipitation effectiveness and temperature efficiency indices, computed for a 6-month season. The basic input data were monthly precipitation and average daily maximum temperature at 48 stations.

"Fire-climate zones" were delineated for Arizona and New Mexico by Fosberg and Furman (1973). These were based on values of an adjusted equilibrium moisture content (e.m.c.) of the fine fuel complex. The e.m.c. was calculated by regression equations using air temperature and relative humidity, applied to afternoon observations at 60 stations. This method does not appear feasible for the coastal Alaska region; one reason is the wide spatial separation between stations observing relative humidity.

"Forest fire weather zones" were drawn for Canada (Simard 1973), based on increments of average June-August values of the Canadian Forest Fire Weather Index (Canadian Forestry Service 1970). These increments were related to a geometric progression of calculated fire intensity. The weather input for the index is the noontime temperature, relative humidity, windspeed, and the preceding 24-hour rainfall.

Returning to coastal Alaska, fire danger was analyzed for the region by Trigg and Noste (1969), utilizing Buildup Index (BUI) and Spread Index values (Nelson 1964) for a

¹U.S. Department of Agriculture, Forest Service, Revision of R-10 fire danger rating. On file at USDA Forest Service Regional Headquarters, Juneau, Alaska.

²Finklin, Arnold I. 1977. Fire-season climatic zones of coastal Alaska. Office report on file at Northern Forest Fire Laboratory, Missoula, Montana.

10-year period, 1956-65. The indices (part of the former National Fire-Danger Rating System) were computed for 11 airport stations and a lighthouse station. Noste (1969) found a relationship between these indices and size class of acreage burned. As indicated earlier, three fire-weather zones were defined for this region (see footnote 1). The zones were characterized according to April-July average precipitation and the average number of days with BUI as high as 30 and 60. The BUI data were from the above 12 stations plus fire-weather stations with shorter records. A BUI value of 30, it was said, could cause suppression problems for a fire in logging slash; at a value of 60, a fire in uncut timber would also be a problem.

DESCRIPTION OF THE REGION; FIRE OCCURRENCE

The geographic region referred to here as coastal Alaska (fig. 1) is divided into two broad areas. These correspond to the general locations of the Tongass National Forest (the southeastern Alaska panhandle) and the Chugach National Forest (the Kenai Peninsula and adjacent south coast, including Afognak Island). The southeast, comprised largely of a group of islands (the Alexander Archipelago), has been described in detail by Harris and others (1974); Federal Power Commission and USDA Forest Service (1947).

The topography of coastal Alaska can be characterized as mountainous and glaciated; though the highest elevations, reaching 7,000 ft (2 000 m) to well over 10,000 ft

(3 000 m), are on the eastern and northern borders of the region. Mountains are generally low on the southeastern islands, allowing a vast expanse of forest from tidewater to a timberline near 2,500 to 3,000 ft (750 to 900 m). Stands here are primarily western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*), with scattered western redcedar (*Thuja plicata*) and Alaska cedar (*Chamaecyparis nootkatensis*). The timberline decreases to 1,000 to 2,000 ft (300 to 600 m) in the Chugach area. Black spruce (*Picea mariana*), white spruce (*Picea glauca*), and paper birch (*Betula papyrifera*) are important species, and the ones with most fire occurrence, on the Kenai Peninsula (Noste 1969).

Annual precipitation over the region (fig. 2) shows the effects of topography, as well as prevailing storm tracks. Normal amounts near sea level range from about 15 inches (375 mm) on the west side of the Kenai Peninsula (outside the Chugach boundary) to more than 100 inches (2 500 mm) over much of the south coast and panhandle; 200 to 250 inches (5 100 to 6 300 mm) occur at a few locations. Amounts are down to 25 to 30 inches (625 to 750 mm) in the extreme northern interior of the panhandle (outside the Tongass boundary). The warmer months of late spring and summer are generally a relatively dry time of year, though normal monthly rainfall may well exceed 5 inches (125 mm) in the wetter areas, particularly in August; drier areas receive 1 to 2 inches (25 to 50 mm). Average daily maximum temperatures generally reach 60° to 65° F (16° to 18° C) by June or July, approaching 70° F (21° C) at some interior locations.



Figure 1.—Map of coastal Alaska (Forest Service, Region 10), showing locations of Chugach and Tongass National Forest (areas highlighted by shading and hatching).



Figure 2.—Average annual precipitation, inches, at stations in coastal Alaska. Mostly based on or adjusted to normal period 1941-70. Solid lines are generalized isohyets drawn at 50-inch intervals; dashed lines are drawn at intermediate 25-inch intervals. Panel A: southeastern panhandle; panel B: Kenai Peninsula and south coast area.



B

The main fire season thus covers the period May through August. Overall, in Region 10, these 4 months account for about 80 percent of all wildfire occurrences and 97 percent of the total acreage burned (Noste 1969). In each of these months, there is commonly a period of a week or more with little or no rainfall. On weather maps, these periods are usually identified with persisting upper-air ridges or patterns of airflow from the north or northeast, which also bring higher daytime temperatures and lower relative humidity. Such features cover large areas; both the normally wetter and drier locations are affected. At some time during an average season, there is apt to be a dry spell of between 10 and 20 days over most of the region (fig. 3). Dry-spell duration reached 37 days at Skagway in 1971. A spell of 23 days in the same year at

normally moist Ketchikan brought extremely high fire danger and a shutdown of nearby logging operations; a 65-acre (26 ha) fire occurred 2 miles (3 km) to the south-east.

Overall, the annual median area burned in Region 10 during the 40 years, 1940-79, was only 53 acres (21 ha); the median number of fires was 25, most of which did not exceed class size A ($\frac{1}{4}$ acre [0.1 ha]). Only 12 of the total reported fires were attributed to lightning; these, all in the Tongass National Forest, burned a total of 2 acres (1 ha). More than 2,500 acres (1 000 ha) burned within or near the Chugach National Forest in 1950 and again in 1959 and 1969; nearly 1,500 acres (600 ha) burned in the south Tongass area in 1958.



Figure 3.—Lengths of dry spells, arbitrarily defined by absence of 24-hour rainfall >0.04 inch (1.0 mm). Lower left number is average seasonal (May-August) maximum length, in days, based on 10-year sample, 1962-71; lower right number is 10-year extreme length. Top number is average 4-month rainfall, inches, for same period.

METHOD, DATA

In order to delineate fire-climate zones for coastal Alaska, it was first necessary to derive the fire-climate classes comprising these zones. To derive the classes in the context of wildfire potential and, also, to utilize simple climatic data providing greatest areal coverage, the following procedure was employed. Average daily maximum temperature for the May-August season and the average 4-month total rainfall were chosen as the climatic parameters. A multiple regression relationship was calculated between these (the independent variables) and a parameter of fire danger (the dependent variable), using the relatively small number of stations for which the latter item could be obtained. The regression was then applied, as a series of curves, to the temperature and precipitation averages at about 100 additional stations. This gave estimated values of the fire-danger parameter. The fire-climate class limits were set in terms of this parameter.

The climatic averages were compiled primarily from summaries published by the U.S. Department of Commerce, Weather Bureau (1958; 1965), and the Weather Bureau's successor agency, the National Oceanic and Atmospheric Administration (NOAA 1973a,b); data since 1960 were tabulated from Climatological Data monthly summaries for Alaska. Additional averages were obtained from the Federal Power Commission and the USDA Forest Service (1947), Patric and Black (1968), and from printout of a tape at the National Fire Weather Data Library at Fort Collins. For greater comparability among stations, the averages were adjusted, where required or possible, to represent the standard 30-year normal period 1941-70. The adjustment entailed use of the "difference method" for temperature and "ratio method" for rainfall (Oliver 1973). Resulting May-August values have been plotted to nearest whole numbers in figures 4 and 5. (See footnote 2 for station names and monthly details.) No

adjustment was made in the temperature averages for effects of differing observation times (Rumbaugh 1934). At airport stations, data are for the actual calendar day; at most other stations, for the 24 hours ending near 4 or 5 p.m. Average maximums in the latter case may be at least 1.0° F (0.6° C) too high.

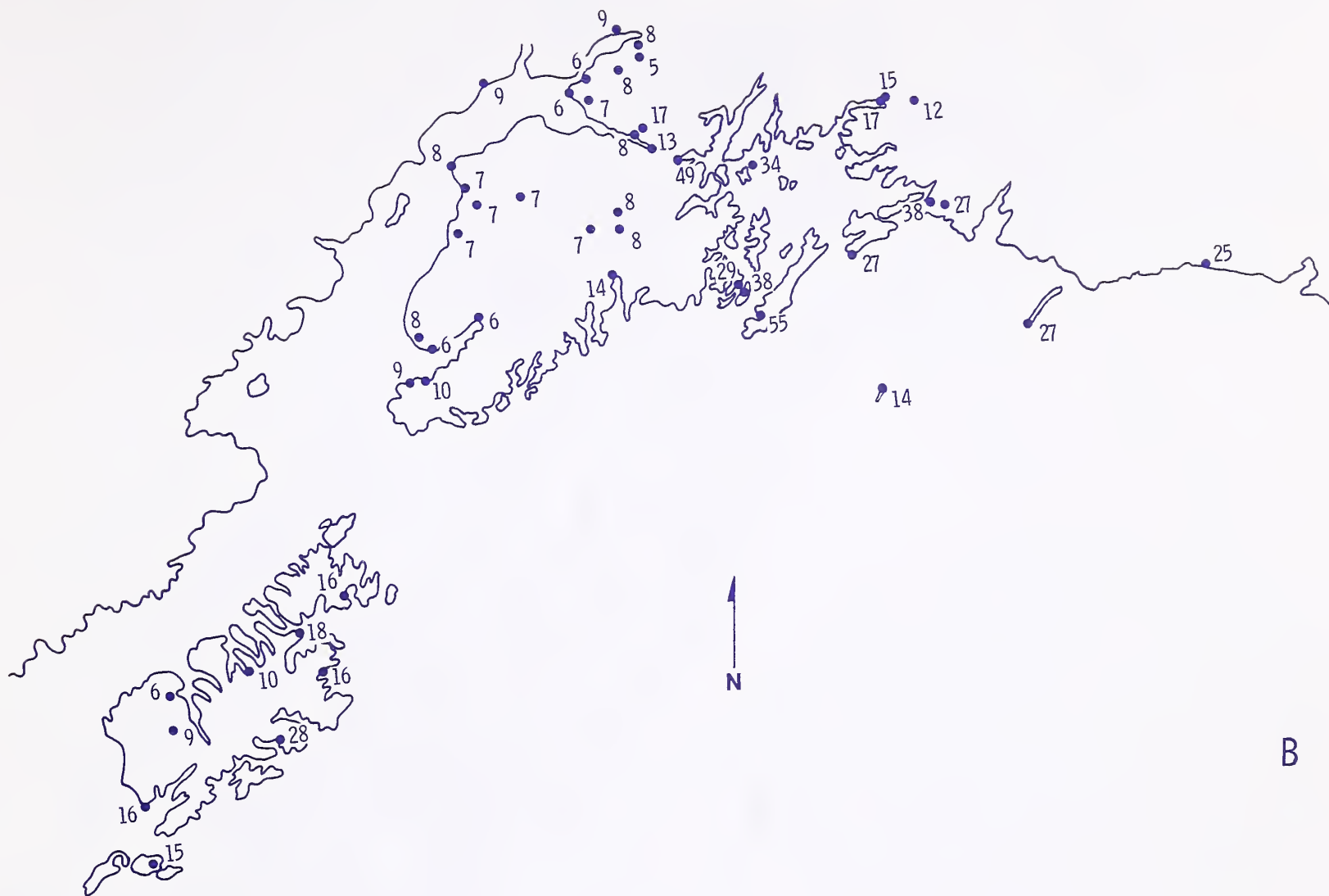
The parameter of fire danger was based on the former BUI, namely the average May-August number of days with a value of 30 or higher. Significance of this value was mentioned earlier. The data were extracted from the reference in footnote 1 and checked with BUI tabulations by Trigg and Noste (1969). As seen in figure 6, the above numbers of days correlate closely with the May-August average BUI values obtained from the Trigg and Noste (1969) reference. Though the BUI has been replaced operationally, past BUI data as employed here can serve as a useful indicator of fire-climate zones.

Efforts to use a fire-danger parameter from the current National Fire-Danger Rating System (Deeming and others 1977), namely the Energy Release Component (ERC), were abandoned. The ERC values were quite different for different periods of years, contrary to the trends of temperature and rainfall. For example, the 90th percentile ERC at Juneau (Federal Building) during 1968-72 was 26, with average 4-month rainfall 23.0 inches (584 mm); during 1973-79, the corresponding percentile from Juneau airport data was 0, with rainfall (at this drier location) 16.7 inches (423 mm). At Sitka airport, the 1968-72 figures were 21 for the ERC and 16.4 inches (417 mm) for rainfall; the 1973-79 figures were 3 and 15.1 inches (384 mm). The ERC value at Ketchikan changed from 18 to 8, and at Thorne Bay from 25 to 16. Much of the problem appears to lie in assumptions that had to be made by the FIRDAT program (Furman and Helfman 1973). The weather observations available prior to 1973 did not contain some items, such as precipitation duration, important for the ERC computations.



A

Figure 4.—Average May-August (4-month) rainfall, inches, at stations in coastal Alaska, mostly based on or adjusted to normal period 1941-70. Panel A: southeastern panhandle; panel B: Kenai Peninsula and south coast area.



B



A

Figure 5.—Average daily maximum temperature ($^{\circ}$ F) for May-August at stations in coastal Alaska, mostly based on or adjusted to normal period 1941-70. Panels as in figure 4.



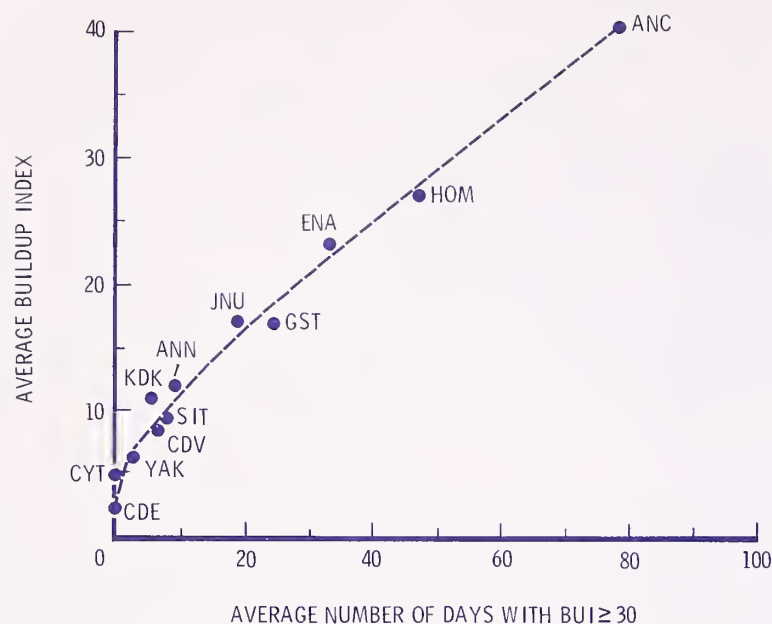


Figure 6.—Relationship between May-August average Buildup Index (BUI) and number of days with value ≥ 30 , coastal Alaska area. Based on 4 p.m. P.s.t. (2 p.m. A.s.t.) observations, 10 years 1956-65. Letters are standard location identifiers (for example, ANC denotes Anchorage; ENA, Kenai; JNU, Juneau; GST, Gustavus; CYT, Yakataga; CDE, Cape Decision).

CALCULATION AND RESULTS

The multiple regression calculation used a computer program from Nie and others (1975). The input data were transformed into logarithms (Freese 1967), as it was evident that the relationship between original variables was curvilinear rather than linear; two of the variables have limiting values of 0.

The assumed equation was:

$\text{LOG } Y = a' + b \text{ LOG } X_1 + c \text{ LOG } X_2$, transformed from a power function

$$Y = aX_1^bX_2^c,$$

where

Y is the number of days with $\text{BUI} \geq 30$ (or number of BUI-30 days),

X_1 is the 4-month rainfall, and

X_2 is the average maximum temperature.

In the logarithmic equation, a' (or $\text{LOG } a$), b , and c are regression constants.

Table 1 lists the input data (before transformation), which are from 18 stations (see fig. 1). Two stations, with zero number of BUI-30 days during the years available, were excluded. Logarithmic transformation would obviously have presented a problem; but, also, the locations, on capes exposed to the open ocean, were considered unrepresentative. Their low BUI values were largely a result of low afternoon temperatures (and associated high relative humidity).

The resulting regression gave a multiple correlation coefficient of 0.95, referring to predicted versus observed values of $\text{LOG } Y$. Even so, some of the differences (or residuals) are large, as seen in figure 7; the values here are transformed back to original units. The regression equation,

$$\text{LOG } Y = -10.596 - 1.520 \text{ LOG } X_1 + 7.638 \text{ LOG } X_2,$$

was used to construct a series of curves (fig. 8) for obtaining estimates of Y and fire-climate class at the large number of additional stations (and for obtaining comparative estimates at the original 18 stations). These curves are drawn for maximum temperature at intervals of 2°F . This element—largely through its influence on relative humidity (Schroeder and Buck 1970)—becomes a more important factor with lower rainfall amounts. The curves do trend toward unrealistically high numbers of BUI-30 days at low rainfall amounts, but (as will be seen) this does not have much practical effect.

Table 1.—Data used for multiple regression, May-August averages

Alaska station	Years	Number of BUI-30 days ¹	Four-month rainfall	Twenty-four-hour maximum temperature
			Inches	$^\circ \text{F}$
Anchorage	1956-65	78.9	6.55	61.2
Angoon	1965-68	23.3	7.75	59.0
Annette	1956-65	9.4	27.16	61.5
Cordova	1956-65	6.5	27.76	57.6
Gustavus	1956-65	24.8	14.78	60.1
Hyder	1966-69	55.4	15.0	² 69.8
Homer	1956-65	47.4	6.29	56.8
Juneau (A.P.)	1956-65	19.2	16.55	60.5
Kenai	1956-65	33.3	7.55	58.1
Kenai Lake	1965-69	86.8	7.30	62.6
Ketchikan	1965-69	3.8	37.23	64.0
Kodiak	1956-65	5.4	15.37	55.4
Petersburg	1965-69	12.8	23.73	61.1
Sitka	1956-69	5.1	23.08	58.5
Skagway	1966-68	83.3	6.49	65.7
Thorne Bay	1965-69	40.2	13.86	² 65.7
Wrangell	1965-69	6.8	19.09	60.9
Yakutat	1956-65	2.9	39.52	57.0

¹Number of days with former Buildup Index (BUI) ≥ 30 .

²Estimated from average dry bulb at 4 p. m. P.s.t.

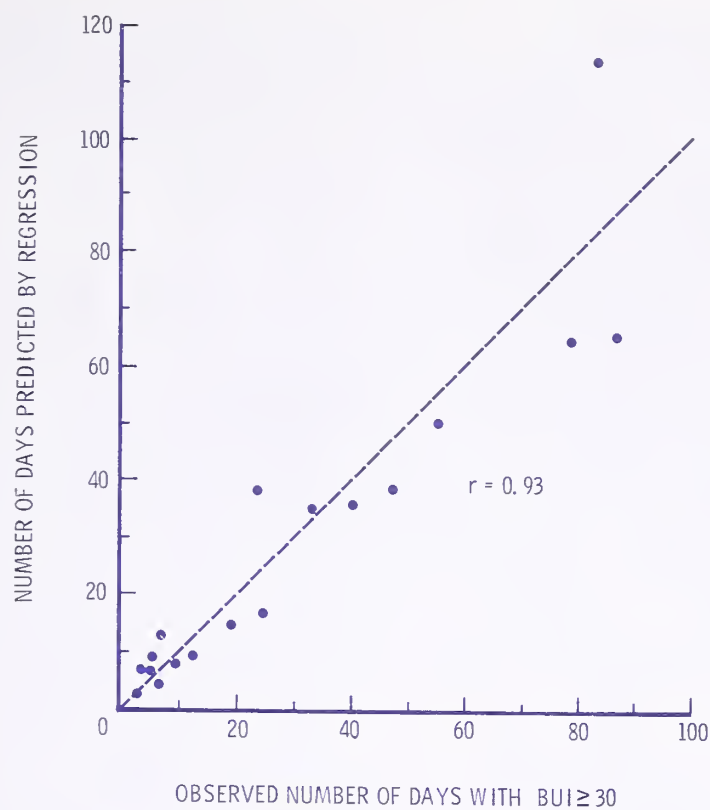


Figure 7.—Observed number of days with Buildup Index (BUI) ≥ 30 versus number predicted by multiple regression. Dashed line represents 1:1 ratio.

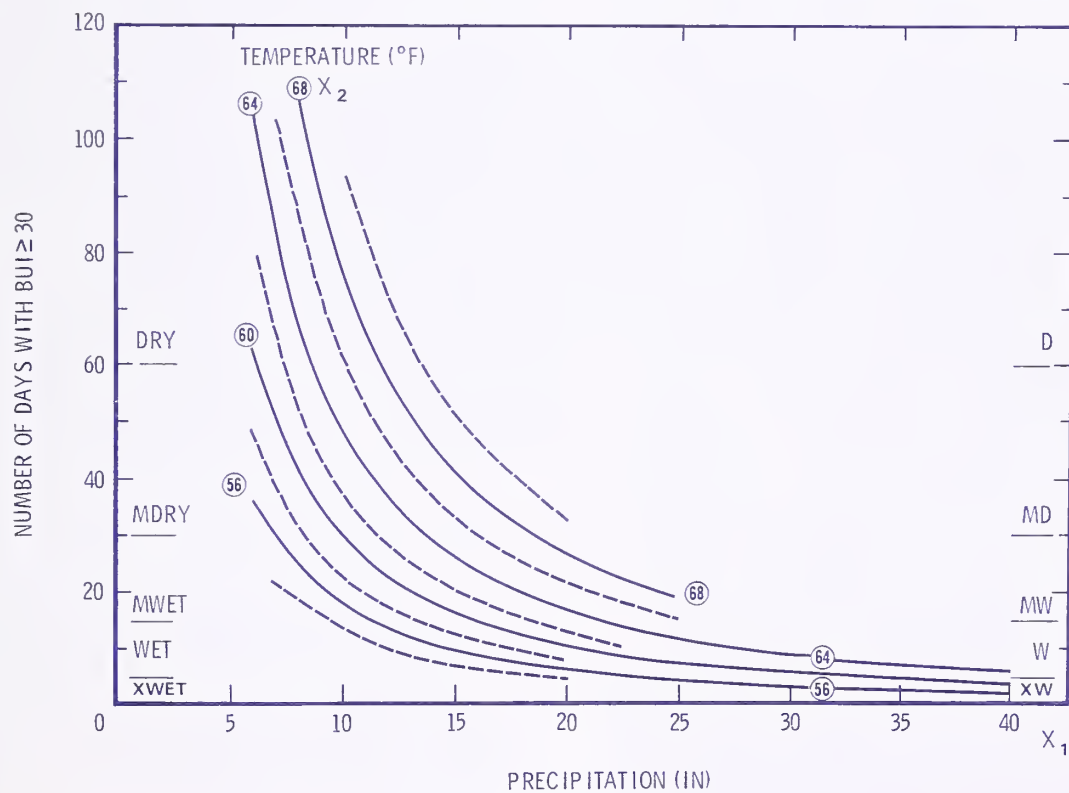


Figure 8.—Curves based on multiple regression equation, for estimating average May-August number of days with Buildup Indexes (BUI) ≥ 30 , given the average 4-month rainfall (X_1) and average daily maximum temperature (X_2). Curves are labeled in degrees Fahrenheit. Horizontal lines at edges denote limits for defined fire-climate classes.

The Fire-Climate Classes and Zones

The derivation of fire-climate classes considered the total number of days, 123, in the May-August fire season. The driest class was arbitrarily defined as having BUI-30 occurrence on one-half or more of all days; the lower limit was rounded to 60 days. For other classes, limits were successively halved to 30 and 15 days. A final, wettest class had an upper limit set at 5 days. This nearly geometric progression concentrates the fire-climate distinction within the range of BUI-30 days covering most of coastal Alaska. The excessive upward trend of the curves already noted in figure 8 occurs mostly outside the range of observed data. Where unrealistically high numbers of BUI-30 days are obtained, the fire-climate class may still be correct, due to the large leeway within the driest class.

The fire-climate classes, included in figure 8, have been named (and abbreviated) as follows: dry (D), moderately dry (MD), moderately wet (MW), wet (W), and extremely wet (XW). The driest class is dry in a relative sense; no stronger designation could realistically be applied anywhere in coastal Alaska.

Based on figure 8 and the temperature and rainfall averages shown in figures 4 and 5, the fire-climate zones have been drawn in figure 9. The boundary lines are, necessarily, generalized. They are drawn to closely fit the BUI results, for stations near sea level, but follow the larger scale topographic features and their inferred influences. The zones refer mainly to the lower elevations of the forest belt.

Summertime upper-air data, available from Anchorage, Annette, and Yakutat (and examined in footnote 2), indicate that the dominant Pacific airmasses usually extend throughout the forest elevations. Nighttime surface temperature inversions from radiational cooling do occur, but "marine" inversions (above which the air is warmer day and night and also much drier) are infrequent. This evidence, together with an indicated increase in precipitation with elevation (Federal Power Commission and USDA Forest Service 1947; Walkotten and Patric 1967; Schmiedege and others 1974), suggests that in general the fire danger buildup decreases with elevation.

The features seen in figure 9 include: (1) a moderately wet zone, up to about 50 miles (80 km) wide, extending through nearly the entire length of the southeastern Alaska panhandle. This zone is situated between wet or extremely wet zones toward the west and east; (2) imbedded moderately dry pockets on at least two of the islands (Admiralty and Prince of Wales); (3) dry or moderately dry areas along the inlets and river valleys in the extreme northern panhandle and extreme east (along the Portland Canal and Taku River); (4) a dry zone covering most of the Kenai Peninsula west of the Kenai Mountain Divide; (5) a strong gradient across this divide to wet and extremely wet zones covering all of the south coast area; and (6) a wet zone over eastern Afognak Island (north of largely unforested Kodiak Island), with a moderately wet zone inferred over inland and sheltered portions to the west.

The pattern in figure 9 roughly follows that of annual precipitation (see fig. 2). In this generalized portrayal of zones, there is no attempt to show an apparent XW zone in the Coast Mountains (for example, east of Juneau and Petersburg), which would not include much forested area.

SUMMARY

This report has presented a method that was used to delineate fire-climate zones in the coastal Alaska area. Climatic data input consisted of simple averages—those of 4-month rainfall and daily maximum temperature during the May through August fire season. Fire-climate classes comprising the zones were derived by a multiple regression using the climatic averages and a fire-danger parameter at 18 stations. This parameter, from a former National Fire-Danger Rating System, was the average number of days with a BUI of 30 or greater (number of BUI-30 days); the value of 30 was previously found to be a threshold with respect to fire suppression in logging slash in coastal Alaska. The regression had high statistical significance; with all data converted to logarithms, the multiple correlation coefficient was 0.95. Curves based on the regression equation were applied to the climatic averages at more than 100 stations.

Five fire-climate classes were defined with limits generally based on a doubling of the number of BUI-30 days; divisions are at 60, 30, 15, and 5 days. The classes are termed dry (D), moderately dry (MD), moderately wet (MW), wet (W), and extremely wet (XW). The delineated fire-climate zones generally represent the lower forested elevations, though the boundaries follow the large-scale topographic features and their inferred influences. The fire-danger buildup in this region appears to usually decrease with elevation (away from open coasts). This is implied by temperature and humidity data from regular upper-air soundings, together with an indicated increase in precipitation with elevation.

Dry zones were defined over most of the Kenai Peninsula west of its major divide and in the extreme northern interior of the panhandle. A few moderately dry areas are found further south in the panhandle—between W or XW zones toward the Pacific Ocean and the eastern mountains—and along river valleys of the extreme east.

The method described here may employ a fire-danger parameter from the current national system. In the present case, lacking much of the required data, such a parameter could not be reliably calculated. The author does not believe that there is as yet one best method or approach; much may depend on the geographic (or broad climatic) region, as well as the type, amount, and quality of data available. In any method, however, defined fire-climate zones should ideally relate to an actual fire-danger index or parameter.



Figure 9.—Fire-climate zones delineated (by dashed lines) for coastal Alaska. Panel A: southeastern Alaska; panel B: Kenai Peninsula and south coast area. D denotes dry; MD, moderately dry; MW, moderately wet; W, wet; XW, extremely wet.

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